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The Demand for Feed Concentrates: A Statistical Analysis

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THE STATISTICAL demand functions presented in this paper were designed to complement recursive livestock supply-demand models, and to provide a basis for appraising feed consumption under alternative programs and for projecting the demand for feed.[1] Although a number of statistical analyses of the demand for feed have been made (2, 5, 6, 7, 8, 12),[2] none of these were oriented toward policy analysis or toward the Department's long-run projections work.

This analysis considers only highly aggregated data. No attempt is made, for example, to estimate the demand for feed by kinds of livestock, nor the demand for specific feeds. Some general questions which such aggregative analyses can help to answer are:

(1) What is the effect of a change in feed or livestock prices on the quantity of concentrates fed?

(2) What will be the effect on total demand for feed of a change in total livestock output or a change in the livestock product mix?

(3) With unrestricted production, at what price would supply and demand for feed be in balance?

Major Conclusions

The great increase in concentrate feeding in the postwar years, and particularly in the last decade, can be largely explained by economic factors. Although technological developments are changing feed conversion rates, the actual level of feeding depends heavily on the economic forces facing the livestock producer. Changes in livestock production (measured by livestock production units)[3] and in prices of concentrates relative to prices of livestock products explain most of the annual variation as well as the uptrend in concentrate feeding during the last decade.

The analyses indicate that a 10 percent increase in livestock production units during postwar years was associated with an average increase of about 13 percent in total concentrates fed, and also in feed grains fed, while use of high-protein feeds increased about 20 percent.

The analyses also indicate that total concentrate consumption rises as the product-feed price ratio improves. A 10 percent increase in this ratio in the postwar years, with livestock production units constant, was accompanied by an increase of about 2-1/2 percent in total concentrate use. Because product prices and feed prices enter into the statistical demand function as a ratio, the elasticity of feed use with respect to livestock price is the same as for feed prices but with opposite algebraic sign. Thus a 10 percent increase in product prices has the same effect on output as a 10 percent decrease in the price of feed.

Demand relations for feed are useful in conjunction with a livestock model to assess the effects of changing feed prices on livestock production, quantity of feed used, and feed consumption rates. In an illustrative example, a decrease in the price of corn of about 30 percent resulted in a 14 percent increase in total concentrates used. This total increase was the product of a 5 percent increase in livestock production units and an 8 percent increase in the feeding rate. Livestock prices declined with the increased livestock output that resulted from lower feed prices, but

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[1] The authors wish to thank Rex F. Daly and Shlomo Reutlinger for many comments and suggestions that have helped to improve this paper.

[2] Underscored numbers in parentheses refer to Literature Cited, p. 49.

[3] The livestock production unit is the sum of all livestock production weighted by feeding rates in some base period (9).

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relatively less than feed prices. This improvement in the product-feed price ratio accounted for part of the rise in the feeding rate.

Postwar Developments in the Feed-Livestock Sector

Total concentrates fed to livestock rose sharply in the postwar period. They increased from 103.7 million tons in 1947-48 to 152.0 million in 1962-63, or nearly 47 percent. The use of high-protein concentrate feeds increased 75 percent, from 10.2 million to 17.9 million tons, during the same period. Consumption of feed grains increased 53 percent, rising from 78.9 million tons in 1947-48 to 120.8 million tons in 1962-63.

Livestock output increased about 30 percent from 1947-48 to 1962-63. Livestock production units--a measure of feed requirements--increased 28 percent in the same period. This increase in livestock production accounted for much of the increase in concentrate use, but higher rates of feeding also contributed.

In standard feed units, which weight all feeds by their nutritive value in terms of corn, feed consumed per livestock production unit rose from 0.690 ton in 1947-48 to 0.787 in 1962-63, an increase of 14 percent (9, 10, 11). Actual weight of feed fed per livestock production unit rose from 0.634 ton in 1947-48 to 0.723 ton in 1962-63, also an increase of 14 percent. The difference in the absolute values of these feeding rates is due to the heavier feeding value assigned to high-protein concentrates in calculating the standard feed unit. We used the widely published actual weight as a basis for analysis, as the year-to-year changes in these two series are about proportional.

Major factors responsible for the increase in concentrate feeding since World War II appear to be:

(1) Improvement in livestock prices relative to feed prices which has encouraged a general expansion in the livestock industry;

(2) More favorable product-feed price relationships which have enabled some individual livestock enterprises to step up the rate of feeding;

(3) Changing composition of livestock and livestock product output;

(4) Technological improvements in poultry production which have brought about multiple increases in broiler and turkey output;

(5) Changes in composition of feeds fed.

During the postwar period, average prices of livestock and livestock products have moved downward, although varying widely primarily because of livestock production cycles. The price index for all livestock declined nearly 12 percent from 1947 to 1962. However, the livestock-feed price ratio increased about 48 percent, as feed prices declined more than livestock prices. Feed grain prices have been under support programs throughout the postwar period. Technological developments in grain production have resulted in rapidly mounting Government stocks, as production increased more rapidly than domestic and foreign markets under existing support prices. With mounting pressure of stocks, price supports were lowered in the latter part of the 1950's. As price supports were lowered, market prices of feed also declined, falling about 40 percent from 1947 to 1962 (fig. 1).

The overall improvement in product-feed price relationships has had both short- and long-run effects on feed use. In the short run, producers have tended to respond to more favorable prices by feeding their existing livestock at higher rates. In the long run, favorable livestock-feed price ratios can result in increased investment in livestock enterprises and expanding output (fig. 2). During 1947-62, moreover, there were two significant changes in the

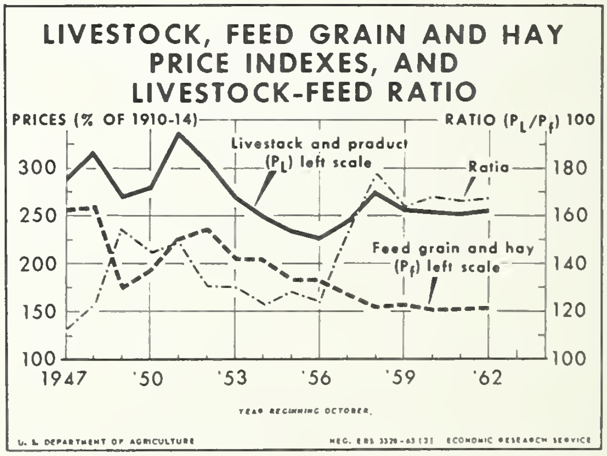

Figure 1

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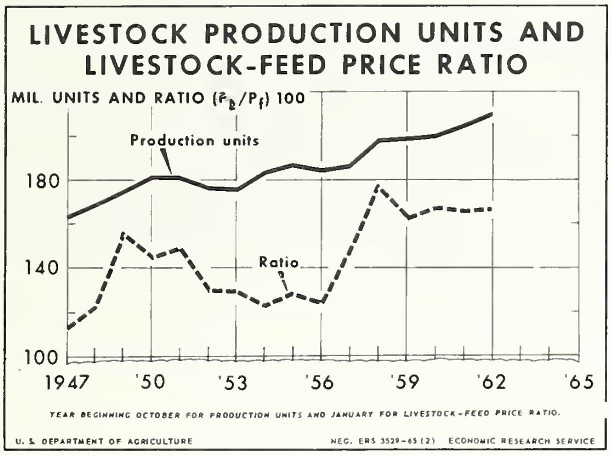

YEAR BEGINNING OCTOBER FOR PRODUCTION UNITS AND JANUARY FOR LIVESTOCK-FEED PRICE RATIO.

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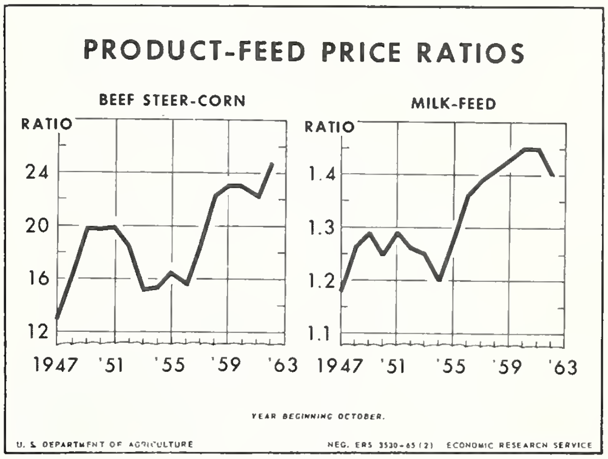
Figure 2

livestock industry which affect feed consumption: changes in the output mix and changes in feeding efficiency. Broiler production increased more than sixfold from 1947 to 1962. During the same period, turkey production more than doubled. Fed beef rose from 34 percent of all beef produced in 1947 to 57 percent in 1960 (3). These increases in poultry and fed beef production had somewhat offsetting effects on the average feeding rate for all livestock. According to available data, broilers currently consume about 2-1/2 pounds of concentrates per pound of product. Fed beef consume over 5 pounds of concentrates per pound of beef added in the feed lot. However, some evidence indicates that this feeding rate for beef may be too low (2).

Significant changes have occurred in livestock production technology in the last two decades. Feeding efficiency in broiler production increased from 26 percent in 1947 to 40 percent in 1962.[4] Without this advance in efficiency, total feed requirements would have been much greater today. On the other hand, feeding efficiency in dairy production apparently has declined as milk production per cow has been pushed to higher levels. Although the quality of dairy cows has improved, higher milk production per cow has been attained mainly by higher feeding rates per cow. From 1947 to 1962, milk production per cow increased 47 percent. Concentrates fed per cow increased about 80 percent and concentrates fed per 100 pounds of milk produced increased about 20 percent in the same period.

Changes in the individual product-feed price ratios appear to explain the increased production of grain-fattened beef and higher output per dairy cow (fig. 3). The beef steer-corn price ratio increased almost 90 percent from 1947 to 1962 while the milk-feed price ratio increased nearly 20 percent.



YEAR BEGINNING OCTOBER.

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Figure 3

Demand for Feed Concentrates

The demand for feed--a factor of production rather than a final good--is derived from, or a function of, the demand for livestock and livestock products. But in another sense, feed demand is a function of the supply of animal products--supply which depends on current production technology, product and factor prices, and other variables. The amount of feed used in any period is the result of all the forces underlying supply and demand for feed-using final products.

The static theory of demand for factors of production under perfect competition is well developed (1, pp. 369-374; 8, ch. 3). However, we need to estimate the demand for feed in its actual dynamic setting. For the analysis reported here, we were guided by economic and statistical theory as well as our practical needs for estimates of feed use that could be integrated with a long-run livestock model. In the relatively simple dynamic analysis which follows, we assume that expected prices are simple functions of past prices and that livestock production units are a relevant demand shifter. The general demand function is as follows:

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[4] Here we define feeding efficiency as pounds of output per pound of concentrates fed.

$$F_t = f(L_t, P_{L_{t-i}}, P_{f_{t-i}}, u_t) \tag{1}$$

where:

F_t = feed use in year t.

L_t = livestock production or inventory in year t.

$P_{L_{t-i}}$ = livestock prices in year t-i.

$P_{f_{t-i}}$ = feed prices in year t-i.

u_t = disturbance in year t.

Statistical Analysis

Several multiple and simple regression analyses were made to obtain estimates of the total demand for feed concentrates and the demand for such major groups as low and high-protein concentrates and feed grains. Least-squares regressions, in linear and logarithmic form, were fitted to the following variables for feeding years 1947-48 to 1962-63. Data used in the analyses are given in table 1. (Feeding years begin October 1.)

Dependent Variables

F_c = total concentrates fed (million tons).

F_{Lp} = total low-protein concentrates fed (million tons).

F_g = total feed grains fed (million tons).

F_{hp} = total high-protein concentrates fed (million tons).

Independent Variables

L_{pu} = total livestock production units (millions).

A_u = total grain-consuming animal units (millions).

H_{pu} = total high-protein animal units (millions).

P_L = index of livestock and livestock product prices received by farmers, 1910-14 = 100, calendar year.

P_f = index of feed grain and hay prices received by farmers, 1910-14 = 100, calendar year.

P_L/P_f = ratio of livestock and product prices to feed grains and hay prices, multiplied by 100.

T = trend, 1947-48 = 1.

Table 1.--Statistical data used in the analysis

Year beginning October 1	Total concentrates fed (F_c)	Feed grains fed (F_g)	Low-protein concentrates fed (F_{Lp})	High-protein concentrates fed (F_{hp})	Livestock production units (L_{pu})	Grain consuming animal units (A_u)	High-protein animal units (H_{pu})	Livestock product prices (P_L) 1910-14 = 100	Feed grain and hay prices (P_f) 1910-14=100	Livestock-feed price ratio (P_L/P_f) 1910-14 = 100	Feed concentrates fed per L_{pu} (F_c/L_{pu})
	Mil. tons	*Mil. tons*	*Mil. tons*	*Mil. tons*	*Million*	*Million*	*Million*	*Index*	*Index*	*Index*	*Tons*
1947......	103.7	78.9	93.5	10.2	163.6	153.1	126.5	288	256	113	0.634
1948......	111.7	88.6	100.4	11.3	168.4	158.6	130.9	315	258	122	.663
1949......	118.3	94.1	106.3	12.0	175.3	163.8	134.2	272	177	154	.675
1950......	121.7	96.2	108.4	13.3	181.5	168.1	136.4	280	193	145	.671
1951......	124.1	98.0	110.7	13.4	181.1	167.3	137.0	336	226	149	.685
1952......	114.0	88.0	100.9	13.1	176.4	158.9	133.8	306	234	131	.646
1953......	116.6	90.7	103.3	13.3	174.7	156.9	133.5	268	206	130	.667
1954......	116.2	90.9	103.1	13.1	183.4	161.6	135.0	249	203	123	.634
1955......	121.9	95.9	107.8	14.1	187.7	165.3	138.4	234	183	128	.649
1956......	119.7	93.6	105.1	14.6	184.1	160.9	136.6	226	182	124	.650
1957......	129.0	101.5	113.8	15.2	186.5	159.9	135.8	244	166	147	.692
1958......	139.5	110.7	123.0	16.5	198.2	167.7	140.8	273	154	177	.704
1959......	144.7	115.8	128.7	16.0	198.7	165.7	139.6	256	156	164	.728
1960......	150.3	120.6	133.5	16.8	202.7	167.6	143.0	253	151	168	.741
1961......	152.9	122.2	135.4	17.5	204.7	169.0	143.4	251	151	166	.747
1962......	152.0	120.8	134.1	17.9	210.1	172.5	146.5	255	153	167	.723

Source: (14, 15).

Table 2 shows the standard regression statistics derived. Elasticities computed at the mean values of the variables are also included. Equations (1.1) and (1.2) estimate the demand for total feed concentrates. These equations follow the general hypothesis stated in equation (1). Both equations account for 96 percent of the total variation in the consumption of feed concentrates over the period. Equation (1.1) predicts feed utilization rather well. Estimated values for total concentrates used, based on equation (1.1), are plotted beside the actual feed used from 1947-48 to 1962-63 in figure 4. In terms of turning points, this equation predicts in the correct direction except for three seasons--1953-54, 1959-60, and 1962-63. However, in 1958-59, the estimated value exceeded the actual value of total concentrate use by 5.9 million tons. This overestimate causes the predicted value of 1959-60 to appear to move in the wrong direction. Equation (1.2) gives comparable results for the analysis period, but because it involves logarithms, it is more cumbersome to use than equation (1.1).

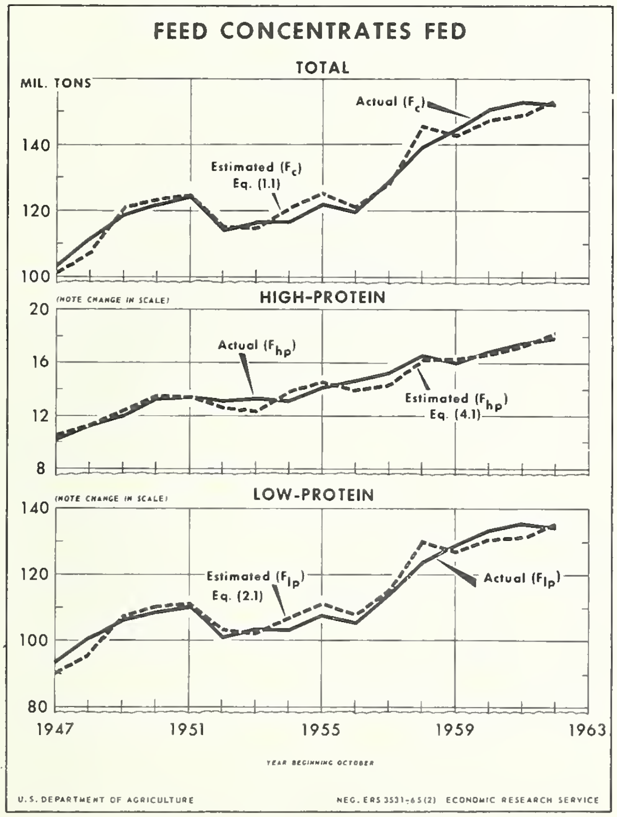

Figure 4

For linear relationships, the elasticity varies at each point on the demand curve. For equation (1.1), the elasticity computed at the mean for feed consumption is 1.28 with respect to livestock production units, 0.25 with respect to price of livestock, and -0.25 with respect to feed grain and hay prices. Evaluation of the variables at 1959-61 levels yields elasticities of 1.19 with respect to L_{pu} and 0.26 with respect to the livestock-feed price ratio. For equations which are linear in logarithmic form, such as equation (1.2), the elasticity is the same at each point on the curve and equals the regression coefficient derived for each variable. Equation (1.2) has an elasticity of feed use relative to L_{pu} of 1.23; that for the product-feed price ratio is 0.26.

Equations (1.1) through (3.1) assume that producers respond to relative livestock-feed prices rather than absolute prices. If this is true, product and factor price elasticities are equal. Some studies of the demand for feed grains used livestock and feed prices as separate independent variables. These analyses resulted in higher elasticities for livestock prices than for feed prices, as might be expected (5, 6, 7). King (12) specified prices of high-protein feed, corn, and livestock as separate independent variables in estimating the demand for feed grains used for feed. In contrast, his analysis yielded a higher absolute elasticity for corn than for livestock prices. This does not seem logical as feed costs are only a part of total costs. The decision to use price ratios in this analysis was based on theoretical considerations as well as exploratory empirical analysis. In two exploratory analyses, the price of feed was specified as a separate independent variable, but the price coefficient was nonsignificant.

In all analyses where livestock-production units were used as an explanatory variable, the elasticity of feed use relative to L_{pu} was greater than one. For example, in equation (1.1), a 1 percent increase in livestock production units was associated with an increase of about 1.3 percent in feed concentrate consumption. When the elasticity of feed consumption with respect to livestock production units is greater than one, the feeding rate increases as livestock production units rise. A similar result was obtained for grain-consuming animal units (5).

Table 2.--Regression coefficients of demand equations for total concentrates, low-protein feeds, feed grains, and high-protein feeds [1] [2]

Equation	Dependent variable	L_{pu}	A_u	H_{pu}	[3] P_L/P_f	T	Constant	R^2
(1.1)....	F_c	0.878 (.115) [1.28]			0.233 (.075) [.25]		-68.053	.96
(1.2)[4]...	F'_c	1.231 (.152)			0.264 (.076)		-1.259	.96
(1.3)....	F_c		0.806 (.599) [1.04]		0.519 (.157) [.58]		-79.466	.81
(2.1)....	F_{Lp}	0.713 (.114) [1.17]			0.233 (.074) [.28]		-51.556	.95
(3.1)....	F_g	0.720 (.103) [1.33]			0.215 (.067) [.30]		-64.470	.96
(4.1)....	F_{hp}	0.165 (.010) [2.15]					-16.493	[5] .95
(4.2)....	F_{hp}			0.425 (.037) [4.08]			-43.956	[5] .90
(4.3)....	F_{hp}					0.454 (.029) [6] [0.03]	10.402	[5] .95

[1] Estimated by least squares. Standard errors are shown in parentheses and elasticities computed at the mean are shown in brackets.

[2] F_c = total concentrates fed
F_{Lp} = total low-protein concentrates fed
F_g = total feed grains fed
F_{hp} = total high-protein concentrates fed
L_{pu} = total livestock production units
A_u = total grain-consuming animal units
H_{pu} = total high-protein-consuming animal units
P_L/P_f = ratio of livestock and livestock product prices to feed grain and hay prices
T = trend

[3] Elasticities are shown with respect to price of livestock and livestock products. Use of a price ratio implies the same absolute value but a negative sign with respect to feed grain and hay prices.

[4] This is a linear equation in logarithms.

[5] Simple correlation coefficient (r^2).

[6] Time elasticity formula:

$$\frac{\dot{F}_{hp}}{\bar{F}_{hp}} \quad \text{where} \quad \dot{F}_{hp} = \frac{d\ F_{hp}}{d\ T}$$

Livestock production units appear to be a better estimator for shifts in feed demand than grain-consuming animal units (9).[5] The relationship based on animal units, equation (1.3), explained only 81 percent of the total variation in feed concentrates fed.[6] Moreover, the regression coefficient of the grain-consuming animal units variable has such a large standard error that it is not significantly different from zero at the 10 percent probability level.

Elasticities, however, derived at the mean for equation (1.3) appear logical. The elasticity of concentrate consumption with respect to A_u is 1.04 and the elasticity relative to the product-feed price ratio is 0.58. Compared with equations (1.1) and (1.2), this analysis gives an elasticity smaller in value with respect to the livestock variable and higher in value with respect to relative prices. Part of this difference in magnitude is explained by lower correlation between grain-consuming animal units and feed concentrate consumption.

Equation (2.1) estimates the demand for low-protein concentrates for feed. Low-protein concentrates in this analysis include the four feed grains (corn, oats, barley, and grain sorghum), wheat and rye, and low-protein byproduct feeds such as flour mill feeds. This analysis explained 95 percent of the total variation in low-protein feed consumed over the period analyzed. All coefficients are statistically significant at the 1 percent probability level. Accordingly, predicted values of this equation follow closely the actual values (fig. 4). Elasticities calculated at the mean for equation (2.1) imply that a 1 percent increase in L_{pu} was associated with a 1.17 percent increase in the consumption of low-protein concentrates, and a 1 percent improvement in the product-price ratio increased consumption by 0.28 percent.

Equation (3.1) estimates the demand for the four feed grains only. This analysis also shows a high correlation as well as logical and statistically significant coefficients. Since we expect substitution to take place in the livestock rations when relative feed prices change, use of separate functions for low proteins, high proteins, and the feed grains may give more accurate results than functions for all concentrates, such as (1.1). Elasticities from table 2 show, on the average, that a 1 percent increase in the number of livestock-production units will increase feed grains fed by 1.33 percent. A 1 percent improvement in livestock prices will increase consumption by 0.30 percent, and a 1 percent reduction in feed grain and hay prices will also increase consumption by 0.30 percent.

In this analysis, high-protein feeds include total oilseed cake and meal, animal protein, and the high-protein grain byproduct feeds. By definition, high-protein concentrates fed plus the low-protein feed concentrates equal total concentrates fed. A comprehensive study of high-protein feed demand was published by King in 1958 (12). The simple analysis presented here deals with a more recent period and the form of the equation is compatible with our general framework for projections.

Several analyses were made to estimate high-protein feed use based on prices of all high-protein feeds, feed grain prices, and other price ratios. However, these analyses were excluded from the paper because of nonsignificant variables and poor predictability.[7] Part of the difficulty in obtaining significant price-quantity relationships for high-protein feeds is due to the ever increasing use of this concentrate. Substantial increases in demand due to unidentified factors have tended to overshadow much of the price influence in recent years.

Technological advances in formula feeding in the postwar period have been sizable (11, 13). Specialized feeds or formula rations, which increased more than 13 percent from 1954 and 1958, are using increasing amounts of high-protein feeds (15). If better managed, larger scale feeding operations based on formula feeds become more prevalent, we may expect high-protein feeds to be used more in line with maximum economic efficiency.

Equation (4.1), which uses livestock-production units (L_{pu}) as a demand shifter, gave somewhat better results than an analysis based on high-protein animal units (H_{pu}), equation (4.2). During the period of analysis, L_{pu} increased at a more rapid rate than the high-protein animal units. Equation (4.3) shows the strong trend ($r^2 = .95$) present in the disappearance of high-protein concentrates (F_{hp}).

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[5] A similar formulation using livestock production instead of production units (4) reports an elasticity of feed use relative to output of 1.0 and .45 for feed use relative to the product-feed price ratio. These relationships were approximated on the basis of changes in the past decade.

[6] Animal units were used as a demand shifter in (5), (6), and (7).

[7] Readers interested in seeing the equations may obtain them from the authors.

The center section of figure 4 compares the predicted values from equation (4.1) with the actual consumption of high-protein feeds. Table 1 also gives the elasticities for the single-variable high-protein equations. On the average, a 1 percent increase in L_{pu} implies a 2.15 percent increase in high-protein feed consumption. The elasticity of high-protein feed fed with respect to the number of protein-consuming animal units (H_{pu}) is 4.08, evaluated at the mean. For the trend equation (4.3) the elasticity shown in table 2 is a time elasticity and is not computed at the mean value.

When the demand for feed concentrates is estimated separately using equations (2.1) and (4.1), the sum of these estimates is about the same as the single aggregate estimate of total concentrate consumption using equation (1.1). The R^2 for the sum of the individual estimates is 0.96. In this sense, the individual estimates are consistent.

A Hypothetical Application

Analyses of the demand for feed can be used as a basis for estimating feed utilization at various levels of livestock production, given prices for feed grains and livestock products. Moreover, demand analyses for feed as presented here can be used in connection with demand and supply response frameworks for the livestock sector of the economy. In these, either the price or the supply of feed grains is given and livestock production and prices are generated by supply response and demand functions.

To illustrate, we estimate livestock production units, livestock prices, and feed consumption on the basis of an integrated livestock model, given the price of corn, technological developments, population, and income growth.[8] Total livestock production units, with corn at 75 cents a bushel, are estimated to be about 5-1/2 percent larger than with corn at $1.10 per bushel (table 3). Prices of livestock products are about 10 percent lower and the livestock-feed price ratio is nearly one-third higher for

Table 3.--Estimated livestock production, feed concentrate use, and feeding rate associated with alternative corn prices

Item	Variable	Unit	Corn price		Percentage change in variable when corn price changes from $1.10 to $0.75
			$1.10	$0.75	
Livestock production units..	L_{pu}	Mil. units	203.0	214.0	5.4
Livestock price index.......	P_L	(1910-14=100)	223	200	-10.3
Feed grain & hay price index	P_f	do.	164	111	-32.3
Livestock-feed price ratio..	P_L/P_f	--	136	180	32.4
Feed concentrate use:					
Total concentrates........	F_c	Mil. tons	140.5	160.0	13.9
Low-protein concentrates..	F_{Lp}	do.	123.5	141.2	14.3
Feed grains..............	F_g	do.	110.9	128.3	15.7
High proteins............	F_{hp}	do.	17.0	18.8	10.6
Aggregate feeding rate......	F_c/L_{pu}	--	.692	.748	8.1

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[8] The model we used was developed by Shlomo Reutlinger and others.

75-cent corn than for $1.10 corn. With these same relationships, feed concentrate use is estimated about 14 percent larger with corn at 75 cents a bushel; low-protein concentrate use is 14 percent larger, feed grain use is nearly 16 percent larger, high-protein feed use is about 11 percent larger, and the overall feeding rate per livestock production unit is about 8 percent higher with corn at 75 cents than at $1.10 a bushel.

Although greatly oversimplified, the above illustrates the relationships, types of information used and generated, and the approximate magnitude of relationships among livestock production, feed and livestock prices, and feed utilization. Estimated feed consumption, the major end use of feed grains, provides a basis for estimating production, as well as acreage and other resources committed for feed production.

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